(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 075 063 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.02.2001 Bulletin 2001/06

(51) Int. Cl.^{7}: H01S 5/0687

(21) Application number: 00114383.3

(22) Date of filing: 05.07.2000

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 05.08.1999 IT TO990692

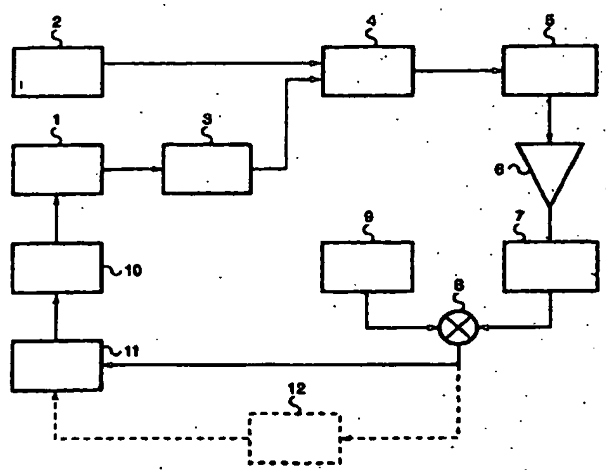
(71) Applicant:
Agilent Technologies, Inc.,
a corporation of the State of Delaware
Palo Alto, CA 94303-0870 (US)

(72) Inventor: Gambini, Piero
10124 Torino (IT)

(74) Representative:
Bosotti, Luciano et al
Buzzi, Notaro & Antonielli d'Oulx
Corso Fiume 6
10133 Torino (IT)

(54) Method and device for stabilizing the emission wavelength of a laser

(57) A process and device are provided for stabilizing the emission wavelength of an optical source (1), which emits radiation at a first wavelength, by locking to the emission wavelength of an optical reference source (2) which emits radiation at a second wavelength which is substantially different from the first. The stabilization device applies to the source to be stabilized a feedback signal obtained by detection of an optical beat between the two radiations. A two-photon absorption for the first wavelength is used to generate the beat.



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Descripti n

[0001] The present invention relates to lasers, and more particularly to a method and device for stabilizing the emission wavelength of a laser source, in which this stabilization is achieved by locking to a reference wavelength which is very different from that which is to be stabilized.

[0002] Preferably, but not exclusively, the invention is applied to the stabilization of the emission wavelength of a semiconductor laser used as the source in an optical communication system.

[0003] It is known that the emission wavelength of lasers is subject to fluctuations, and therefore the lasers are associated with control circuits which detect the deviation from the nominal value and generate an error signal which is sent to the laser operating devices to keep the emission wavelength at this nominal value.

[0004] In a commonly used stabilization method, the emission wavelength of the laser is locked to an atomic or molecular line, e.g. an absorption line of a gas which has an absorption spectrum with lines whose wavelength is close to the emission wavelength of the source. An example of a locking method of this type for the application, preferred here, to the field of optical telec mmunications, is described in European Patent 0 660 470. This stabilization is absolute, in other words independent of the environment, and provides the source with good short- and long-term stability and good reproducibility of the emission wavelength.

[0005] In general, however, atomic or molecular lines close to those used for optical telecommunications are relatively wide and therefore the stabilization achieved may be insufficient. For this reason, numerous pr posals have been made in the literature for the provision of locking on absorption lines at wavelengths relatively distant from that of the source to be stabilized, which have more advantageous characteristics for the intended purposes. An example is that of an absorption line of rubidium at 780 nm. Absorption lines at this wavelength are used for the purposes of stabilization in various fields, including those which are very different from telecommunications (e.g. metrology).

[0006] However, it is generally difficult to produce wavelength comparison systems for signals having very different wavelengths from each other, and therefore attempts are made to bring the wavelengths for comparison closer to each other.

[0007] The article "Absolute Frequency Control of a 1560 nm (192 THz) DFB laser locked to a Rubidium Absorption Line Using a Second-Harmonic-Generated Signal", by C. Latrasse and others, IEEE Transactions on Instrumentation and Measurement, vol. 44, no. 4, August 1995, pp. 839 ff., describes a system in which the radiation at 1560 nm mitted by the laser to be stabilized is directed into a crystal of $KNbO_3$ which generates its second harmonic (corresponding to a wavelength of 780 nm). This second harmonic is separated from the main signal at 1560 nm and sent to a cell containing ^{87}Rb for interaction with the line at 780 nm. The signal leaving the cell is subsequently detected in a silicon photodiode to produce the error signal to be supplied to the laser control devices.

[0008] Other methods, such as those described in the articles "Wide-Span Optical Frequency Comb Generator for Accurate Optical Frequency Difference Measurement", by M. Kourogi and others, IEEE Journal of Quantum Electronics, vol. 29, no. 10, October 1993, pp. 2693 ff., and "Generation of Frequency-Tunable Light and Frequency Reference Grids Using Diode Lasers For One-Petahertz Optical Frequency Sweep Generator", vol. 31, no. 3, March 1995, pp. 456 ff., produce the stabilization by locking the laser source to be stabilized to a highly stable reference source. For this locking, optical signals with a frequency equal to the sum of and/or the difference between the frequencies of the two sources are generated, and the beat signals are detected. These beat signals are then fed back to act on the laser to be controlled.

[0009] In all these known methods, the creation of the error signal requires two separate operations: the first is the generation of an optical signal at a suitable frequency by the generation of a harmonic of the signal to be stabilized (in the case of the first document cited) or the mixing of this with a reference signal; the second operation is the detection of the converted signal. This makes the corresponding equipment complicated and makes the process inefficient.

[0010] The object of the invention is to provide a method and equipment which enable this disadvantage to be overcome.

[0011] According to the invention, a method is provided for stabilizing the emission wavelength of an optical source which emits coherent radiation at a first wavelength, by locking to the emission wavelength of an optical reference source, which emits coherent radiation at a second wavelength which is substantially different from the first, in which method the radiations at the first and second wavelengths are made to interact optically, an optical signal resulting from the interaction is detected, a feedback signal is produced from the detected signal and applied to the source, and the said interaction is represented by a two-photon absorption for the first wavelength, which gives rise to a beat signal having a frequency equal to the difference in frequency between a radiation at a wavelength which is half the first wavelength and the second radiation, this beat being detected concurrently with its creation.

[0012] The invention also relates to the device for implementing the method.

[0013] The phenomenon of two-photon absorption is a non-linear phenomenon based on the fact that two photons which are coherent in phase can interact to excite an electron in a semiconductor material to an energy twice that of a single photon. Owing to this phenomenon, a coherent radiation to which the material

would be transparent can be absorbed, thus generating electron-hole pairs. These can then be detected as a photodetection current or as luminescence. A fuller description of the phenomenon can be found, for example, in "Optical processes in semiconductors" by J.I. Panhove, Dover Publications, Inc., New York, USA, 1971: see, in particular, Sections 12-A-4 and 12-A-5 on pp. 268 ff.

[0014] For additional clarification, reference should be made to the attached drawing, which shows a preferred embodiment of the device according to the invention.

[0015] The device according to the invention can be used to stabilize a source 1 to be stabilized, which operates at a wavelength L1, by locking to a reference source operating at a wavelength L2 which is very different from L1. In particular, by way of example and without restrictive intent, reference will be made in the following text to a source 1 which emits radiation in the third optical communication window (in particular at 1560 nm) and a reference source 2 which emits at 780 nm. Clearly, the reference source 2 must be a highly stable source. The method by which the source 2 is stabilized has no effect for the purposes of the present invention. In the example under consideration, in which the source 2 emits at 780 nm, the stabilization can be carried out by locking to an Rb absorption line.

[0016] The radiation to be stabilized (subjected to polarization control in an entirely conventional control device 3 if required) and the reference radiation are supplied to a dichroic coupler 4 which supplies the two radiations to a device 5 capable of making the two radiations interact by means of the phenomenon of two-photon absorption for the higher wavelength L1, and of d tecting an optical beat resulting from the interaction.

[0017] This beat, because of the nature of the two-photon absorption, has the frequency $|2f_1-f_2|$, where f_1 and f_2 are the frequencies corresponding to the wavelengths L1 and L2. This sets a limit to the difference between the two wavelengths, which must be such as to permit the detection of the beat by means of the device 5 which is used.

[0018] As widely reported in the literature, devices in which two-photon absorption is carried out for radiation with a wavelength of approximately 1.5 μm can be silicon avalanche photodiodes, LEDs of various types, or laser diodes.

[0019] When two-photon absorption is used, the operation of combining the two wavelengths and the detection of the resulting signal take place in a single device, thus simplifying the structure. Moreover, the use of a dichroic coupler prevents losses in the superimposition of the fields of the two radiations whose beat is created. A further advantage of the solution according to the invention is that no optical filtering is needed to eliminate unwanted products of the combination, whereas this would be required by methods based on the generation of the sum of, and difference between, the frequencies of the radiations which are made to interact.

[0020] Clearly, in order for the two-photon absorption to take place, the source 1 must have a sufficiently high power, e.g. a power of the order of a few tens of mW.

[0021] To simplify the drawing, the means (e.g. optical fibres) for carrying the radiations to the dichroic coupler 4 and from this to the device 5 are not shown.

[0022] The output signal of the device 5, which as stated above is a signal at the frequency $|2f_1-f_2|$, is amplified in an amplifier 6, filtered in a band-pass filter 7 to reduce the noise and compared in a mixer 8 with a signal at radio frequency generated by a high-stability electronic oscillator 9, in order to produce a feedback signal for the laser 1. This signal will be supplied to the control devices 10 of the laser 1 in a conventional way through a loop filter 11.

[0023] The frequency of the oscillator 9 can be selected according to the beat frequency and the type of feedback which is to be produced. In particular, it is possible to use an oscillator 9 with a frequency equal to that of the beat created by the device 5: in this case, the mixer 8 can act directly as a phase discriminator and its output signal can be used directly to drive the laser. If the frequency of the oscillator 9 is different from the beat frequency, the mixer 8 will supply a signal at a frequency equal to the frequency difference between the signal supplied by the oscillator and the detected beat signal, and in this case the feedback signal will be obtained by means of an electronic frequency discriminator 12, of any known type, as indicated in broken lines in the figure. This is also the case when the detected beat signal is to be used directly.

[0024] Clearly, the above description is provided solely by way of example and without restrictive intent, and variants and modifications can be produced without departure from the scope of protection of the invention.

Claims

1. Method for stabilizing the emission wavelength of an optical source (1) which emits coherent radiation at a first wavelength, by locking to the emission wavelength of an optical reference source (2), which emits coherent radiation at a second wavelength which is substantially different from the first, in which method the radiations at the first and second wavelengths are made to interact optically, an optical signal resulting from the interaction is detected, and a feedback signal is produced from the detected signal and applied to the source (1) to be stabilized, characterized in that the said interaction is represented by a two-photon absorption for the first wavelength, which gives rise to a beat signal having a frequency equal to the difference in frequency between a radiation at a wavelength equal to half the first wavelength and the second radia-

tion, this beat being detected concurrently with its creation.

2. Method according to Claim 1, characterized in that the said first wavelength is substantially twice the second wavelength.

3. Method according to Claim 2, characterized in that the said first wavelength is a wavelength in the third transmission window for optical communications.

4. Method according to any one of the preceding claims, characterized in that the detected beat signal is mixed with a highly stable radio frequency signal for the generation of the feedback signal..

5. Method according to Claim 4, characterized in that the said radio frequency signal has a frequency equal to that of the detected beat signal, and the signal resulting from the mixing is used as a feedback signal.

6. Method according to Claim 5, characterized in that the said radio frequency signal has a frequency different from that of the detected beat signal, and a signal obtained by frequency discrimination of the signal resulting from the mixing is used as the feedback signal.

7. Device for stabilizing the emission wavelength of an optical source (1), which emits coherent radiation at a first wavelength, by locking to the emission wavelength of an optical reference source(2), which mits coherent radiation at a second wavelength substantially different from the first, comprising means (5) for making the radiations at the first and second wavelengths interact and means (6-9, 11; 6-9, 11, 12) for producing, from a signal resulting from the interaction, a feedback signal which is applied to devices (10) for controlling the source (1) to be stabilized, characterized in that the means (5) of interaction and detection form a single device, adapted for carrying out a two-photon absorption for the first wavelength.

8. Device according to Claim 7, characterized in that the said source to be stabilized (1) is adapted for emitting radiation at a wavelength which is substantially twice the wavelength of the radiation emitted by the reference source (2).

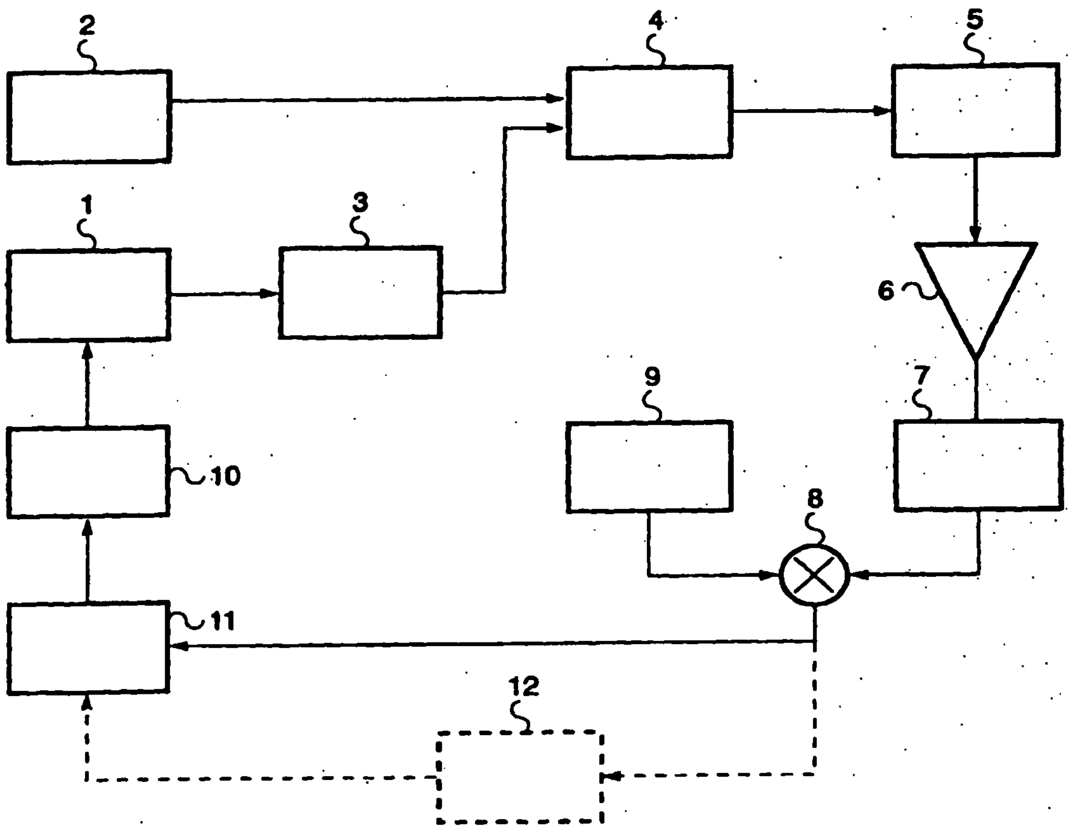
9. Device according to Claim 8, characterized in that the said source to be stabilized (1) is adapted for emitting radiation at a wavelength in the third transmission window for optical communications.

10. Device according to any one of Claims 7 to 9, characterized in that it comprises a dichroic coupler (4) for supplying the radiation emitted by the sources to the device (5) which carries out the two-photon absorption.

11. Device according to any one of Claims 7 to 10, characterized in that the means (6-9, 11; 6-9, 11, 12) for producing the feedback signal from the detected beat signal comprise means (8) for mixing the detected beat signal with a radio frequency signal generated by radio frequency generating means (9).

12. Device according to Claim 11, characterized in that the said generating means (9) generate a signal at a frequency equal to that of the detected beat signal, and the said feedback signal is the output signal of the mixing means (8) which operate as phase discriminator means.

13. Device according to Claim 12, characterized in that the said generating means (9) generate a signal at a frequency different from that of the detected beat signal, and the said mixing means (8) are connected to frequency discriminator means (12) which supply the said feedback signal.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11.09.2002 Bulletin 2002/37

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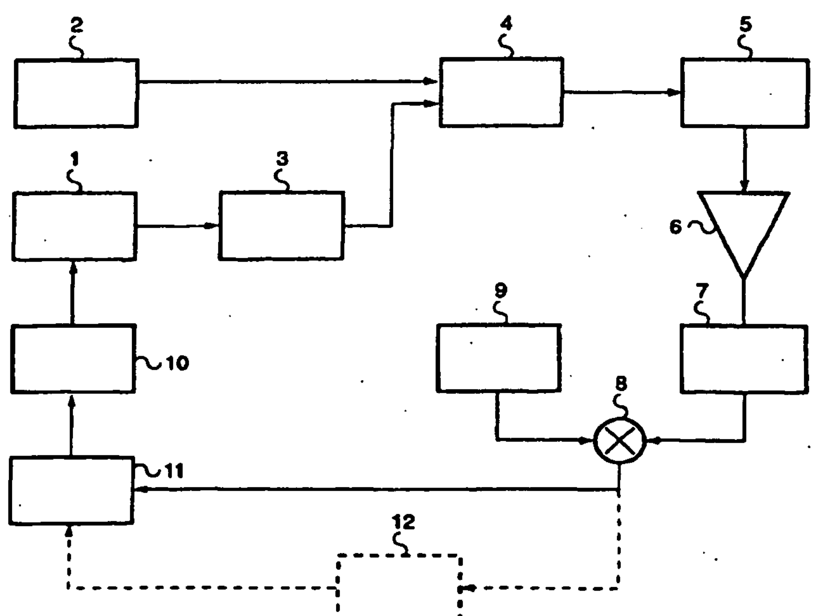

EP 1 075 063 A3

Printed by Jouve, 75001 PARIS (FR)

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EUROPEAN SEARCH REPORT

Application Number
EP 00 11 4383

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 440 207 A (OTSUKA KAZUE) 8 August 1995 (1995-08-08) * abstract * * column 3, line 27 - column 4, line 14 * * figure 3 *		H01S5/0687
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 11, 30 September 1998 (1998-09-30) -& JP 10 173602 A (NEC CORP), 26 June 1998 (1998-06-26) * abstract *		
A	US 4 817 101 A (WYETH RICHARD W ET AL) 28 March 1989 (1989-03-28) * abstract * * figure 16 * * column 1, line 37 - column 1, line 47 * * column 15, line 1 - column 15, line 45 *		
A,D	EP 0 660 470 A (CSELT CENTRO STUDI LAB TELECOM) 28 June 1995 (1995-06-28) * claim 3 * * figure 1 *		TECHNICAL FIELDS SEARCHED (Int.Cl.7) H01S H04B

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	16 July 2002	Sauerer, C

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A,D	MOTONOBU KOUROGI ET AL: "WIDE-SPAN OPTICAL FREQUENCY COMB GENERATOR FOR ACCURATE OPTICAL FREQUENCY DIFFERENCE MEASUREMENT" IEEE JOURNAL OF QUANTUM ELECTRONICS, IEEE INC. NEW YORK, US, vol. 29, no. 10, 1 October 1993 (1993-10-01), pages 2693-2701, XP000423090 ISSN: 0018-9197 * page 2694, column 1, paragraph 3 - page 2695, column 2, paragraph 1 * * figure 1 * * figure 3 * -----		

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

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